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BIOGAS PRODUCTION POTENTIAL FROM VARIOUS BIOMASS WASTES: A REVIEW

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ABSTRACT

This review paper mainly associated with the biogas generation potential from different available feed stock and different wastes through anaerobic digestion. Feedstock composition is one of the major factors that affect the production of biogas. High production of methane depends mainly on the substrate used singly or in combination of two or more substrates as feeding material. However, the difference in total methane yield varies based on the type of interactions between different wastes that interfere with digestibility of wastes in the digester. In this review, percentage of methane content (the main constituent) in biogas produced from different digestible materials is almost the same. In this paper, the work on biogas production from different wastes by authors is reviewed and it was suggested from their work that the poultry wastes produce more biogas than poultry droppings. Mixing of cow dung with JS, especially in the 2:1 ratio produced optimum gas yield, its quality and plant nutrient values. The study also revealed that the cotton wastes can be treated an aerobically and are a good source of biogas. Kitchen waste has high calorific value and nutritive value to microbes due to which efficiency of methane production can be increased by several orders of magnitude. Likewise, if the faecal sludge co-digest with various types of organic feedstock materials will also be effective in producing biogas and nutrient rich bio-slurries as organic fertilizer.

***Keywords*: Biogas, Biomass, Co-digestion, Cow dung, Kitchen wastes, Agricultural wastes, Sludge**

Introduction

Mankind has experienced many changes over the millennia. The greater portion of the advances in innovation has happened recently in the last two decades. The exploration of coal and oil as energy sources changed the core of how we achieve things like nothing else since the discovery of fire. Be that as it may, these petroleum products do not exist in an endless supply, making it important to investigate the other significant alternatives. One such alternative is biomass as a source of vitality. Biomass is a most generous asset on the planet. By definition, it is the mass of living or freshly dead plants and creatures, alongside their wastes. This implies that there is not a solitary square centimetre of earth that does not hold some type of biomass that could be changed over to renewable energy. Fossil fuel is the predominant source for energy production worldwide since the last century (DeMarco, 2017) and combustion of fossil fuels generates CO_2 and other noxious gas which results into many changes our climate all over the world. However, there is increase in energy demand and the issues about current non-renewable energy resources led researchers to explore diverse clean energy sources in the last few decades. The production and use of biogas energy is one of the important sectors of renewable energy sources in the world. In a number of countries, bioenergy has taken an important part in the energy balance for the production of electricity from agricultural and livestock waste, food industry waste, selected household waste (food, paper, etc.), energy-rich plants (corn, grass, etc). Renewable energy resources draw attention all over the world because they are sustainable, improve the environmental quality and provide new job opportunities in rural areas. Anaerobic digestion (AD) process is historically one of the oldest processing technologies used by mankind. Today biogas technologies, which are based on anaerobic fermentation of the initial product, are operating in more than 65 countries of the world, namely in the USA, France, Great Britain, China, India and others. The anaerobic digestion is a biological degradation of organic matter by microbial flora in anaerobic condition. One such resource is the waste organic matter that is generated in the kitchens and one of the natural agencies which will play an important role in this utilization is the tiny part of the huge world of tiny microbes. Anaerobic digestion has been considered as waste-to-energy technology, and is widely used in the treatment of different organic wastes, for example: organic fraction of municipal solid waste, sewage sludge, food waste, fish waste, animal manure agricultural wastes, etc. According to Donkin *et al.* 2013 about 15 billion tons of waste, like crops residues and animal manure is generated worldwide annually from the agricultural Sector and their suitability for biogas production potential varies significantly depends on the composition and the biodegradability under anaerobic conditions. Biogas is a clean renewable energy produced from organic wastes using anaerobic digestion as a method. The products of the digestion are biogas and residue. Biogas is a mixture of methane (CH_4) with percentage over than 60% and carbon dioxide (CO_2). CH_4 is the highest component of natural gas. Methane is the main combustible gas in biogas. The bio gas is useful as a fuel substitute for firewood, dung, agricultural residues, petrol, diesel, and electricity, depending on the nature of the task, and local supply conditions and constraints, thus supplying energy forcooking and lighting. Biogas systems also provide a residue organic waste, after anaerobic digestion that has highly superior nutrient qualities over the usual organic fertilizer, cattle dung, as it is in the form of Ammonia.

Beside energy production, the degradation of biomass waste through anaerobic digestion offers other advantages, such as the prevention of odour, disposal solution and improvement in sanitation by destroying pathogens during the process. Moreover, the nutrient rich digested slurry can be utilized as fertilizer for recycling of nutrients back to the fields. Another advantage offered by biogas is to lead to a net reduction of greenhouse gas emissions, since methane would otherwise be released into the atmosphere, provoking a 21-fold higher greenhouse effect than CO_2. Therefore, it is important to treat organic wastes under controlled conditions to reduce spontaneous dissipation of methane to the atmosphere. The production of biogas will minimize the use of fossil fuels, thereby reducing the greenhouse gas emission, which is in line with Kyoto Summit Agreement.

Despite its several advantages, the potential of biogas technology could not be fully harnessed due to limitations associated with the production of biogas. Notably common among these are the large hydraulic retention time (HRT), low gas generation in winter, etc. In an agrarian nation like India where rural electrification is limited and commercial fuels make up only 11% of rural energy use, biogas could go a long way toward improving the energy security and environmental future. Therefore, efforts are needed to remove its constraints and to make this technology more feasible for industrial production and in reach of the rural population. Researchers have examined different biomass wastes from variety of sources to enhance gas production. This review article provides a critical analysis of recent research advancement of biogas production from variety of biomass available.

Biogas Production from Different Biomass Sources

Different biomass wastes used for biogas generation reviewed by different workers is discussed under following categories (Table 1):

Cow Dung, Poultry Waste and Swine (Table 1 A)

Imam *et al.* (2013) investigated that the cow dung and poultry waste as animal waste has great potentials for generation of biogas and its use should be encouraged due to its early retention time and high volume of biogas yields. It was observed that biogas production from cow dung, poultry waste and water hyacinth is 0.034 m^3/kg, 0.058 m^3/kg and 0.014 m^3/kg respectively. Poultry waste produced maximum gas 0.026 m^3 at the 8th day whereas cow dung and water hyacinth produced maximum gas 0.0263 m^3 and 0.012 m^3 respectively at the 26^{th} day. Sangeetha *et al.* (2014) investigated the comparison of viability of biogas from poultry waste and the mixture of poultry and fish waste. Fish wastes have great potential as a source of high valued organic carbon for methane production and have high content of ammonia nitrogen. In our study we found that the poultry wastes produced more biogas than poultry droppings. They co-digested poultry waste and cow dung in the ratio of 3:2 and also co-digested poultry waste with the mixture of fish waste and cow dung in the ratio of 2:2:1 in capacity about 20 liters digesters. The rise in barine solution level was different for both mixture of waste. For the mixture of poultry waste and cow dung the rise in level was 2.75cm and for the mixture of poultry waste, fish waste and cow dung the rise in level was 6.2 cm by using water displacement method.

Biogas was collected in water bottles containing barine solution of sodium hydroxide and the rise in solution level indicates the amount of biogas produced by anaerobic digestion. After 2 weeks of digestion results showed that there was significant rise in the barine solution level indicating the biogas production was high in the mixture of poultry waste, fish waste and cow dung. Yavini *et al.* (2014) carried out study to determine the kinetics of agricultural wastes biogas production when inoculated with cow dung/poultry droppings under mesophilic conditions with 8% total solids and 55 days retention time. The modified first order kinetic model was developed to access the kinetics of the biodegradation of the digestion process. A plot of 1/t(ln(dyt/dt)) against 1/t from the model gives the rates of substrate biodegradability and removal of the biodegradable fractions of the substrate. The result shows that maize cobs (MC) has the highest short term biodegradability index of 1.5827 while bio-digester, Sugarcane Bagasse (SB) has the lowest rate of the biodegradable fractions (k) of -0.302 among all the substrates (Groundnut Shell [GS], Maize Cob [MC], Rice Straw [RS] and Sugarcane Bagasse [SB]). Bio-digester C (Rice Straw) has the highest yield of biogas (31.50 ml/g VM) with cumulative volume of 692.9 ml and an R^2 value of 0.8424 while bio-digester D (Sugarcane Bagasse) has the least of 185.9 ml and an R^2 value of 0.6479. Cu *et al.* (2015) estimated that the Piglet manure produced the highest methane yield at 443 NL (Normal litter) CH_4 (kg VS^{-1}), followed by cow, rabbit, goat and sheep manure at, respectively, 222, 172, 169, and 150 NL CH_4 (kg VS^{-1}). Methane production from duckweed was higher than that from grass and water spinach at 340.6, 220, and 110.6 NL CH_4 (kg VS^{-1}), respectively. Inhibitors were found in the Biochemical Methane Production (BMP) experiment in pig slaughter waste, fish waste, chicken manure, cassava residues, shoe-making waste and household waste. An equation was developed to predict methane potential from the chemical compositions of biomass with an R^2 of 0.96 for the animal manure biomass group and 0.95 for the combined animal and plant biomass group. Lipid, lignin, protein, and cellulose contents in biomass were the best predictors of BMP value. Manimuthu *et al.* (2017) demonstrated that the yield of biogas was comparatively better by the alternate biomass used with the digestion of various waste materials such as Cow Dung(CD), Rumen(RU), Agar Waste(AW) and Sewage Sludge (SS) in 5 litre of glass bottles working volume on a batch reactor for over 40 days. The preparation of slurry in different ratio of mixture of wastes the control of CD,RU,AW and SS, 1:1 ratio of RU:AW, AW:SS, SS:RU and 1:1:1 ratio of RU:AW:SS. There was designated in T_0, T_1, T_2, T_3, T_4, T_5, T_6, and T_7 respectively. All the treatments were prepared in triplicates. Biogas production was measured indirectly water displacement method. The results indicated that the mixture of 1:1:1 ratio (T_7) slurry provide the higher biogas yield of 3886.30ml and then followed by T_2, T_3 and T_6 treatments gave average yield of 3190.35, 2068.65 and 1804.51ml. From the outcome of the study it was proposed that the utilization of these substrates for biogas production could eliminate its disposal problems and create another abundant source of sustainable energy. Yitayal *et al.*(2017) probed the experimental studies on anaerobic digestion of *Justicia schimperiana* (JS) and cow dung each separately and with their various combinations at Addis Ababa University Environmental Science Laboratory, Ethopia. The results revealed the estimation of biogas production and methane content of each treatment, T1 (cow dung alone), T2 (1:1), T3 (2:1), T4 (3:1), T5 (JS alone), T6 and T7 (with digester effluent) was performed using indirect (water displacement) and absorption of CO_2 by 10% NaOH methods, respectively. Statistically significance difference (at 0.05 levels) on production of biogas among treatments was observed. It was found that T5 (JS alone) was highest in the amount of biogas production but lowest in its quality (i.e., methane content) and T3 (2:1 ratio of cow dung to JS) was the second highest in the amount of production, but the highest in quality. Thus, T3 produced the optimum methane gas among treatments. Moreover, JS and its combinations with cow dung produced higher volume of biogas and contained more macro-nutrient in the slurry for plants than cow dung alone. Thus, JS appears to be a good material for biogas and bio-slurry production. Rekha *et al.* (2019) carried out experiments on co-digestion of cow dung with poultry manure and vegetable waste. The highest yield of biogas was obtained from the co-digestion of cow dung with poultry manure i.e. .063m^3. The production of biogas using 1:1 ratios of cow dung and water is 0.049m^3. The production of biogas using co-digestion of cow dung with vegetable waste using 1:1 ratio is 0.052m^3. They concluded from the study that the production of biogas from co-digestion of wastes found more than the individual waste. Lakkimsetty and Mushaarafi (2019) demonstrated that the biogas production was carried out from animal, kitchen and trees waste by anaerobic digestion process. It was observed that the animal waste was produced the highest amount of biogas compare to the other type of organic wastes. The amount of biogas produced from animal, kitchen and trees wastes was $0.03m^3$, 0.024m3 and $0.0103m^3$ respectively. Furthermore this study suggested that biogas production process could give a promising evidence of the anaerobic digestion as a viable and feasible treatment technology of organic waste, in particular, the animal manure simultaneously generating biogas as the renewable energy.

Biogas Production From Weeds (Table 1B)

Islam (2012) studied the biogas production (Batch Process and Continuous process) from Pterislongifolia (DhekiShak) and Water Hyacinths which are very common weeds in Bangladesh. It was observed from the study that the biogas production in batch process mixture of the weeds yields 2018ml while cow dung yields 1375 ml that means the mixture yields 1.5 times more than only cow dung. While in continuous process, Water Hyacinths yield 946 ml and 884 ml respectively. It indicates that the variation in two reactors is 6.5%. The average gas production is 915ml. In continuous process Dheki Shak yields 2254 ml and 2507 ml in two reactors. The variation is 10% and the average gas production is 2380 ml. In continuous process mixture of the weeds yields 5973 ml and 5223 ml in two reactors showing the variation 12.5% and average yield 5600ml. Total gas yield from mixture is 2 times greater than individually Dheki Shak and 6 times greater than Water Hyacinths. From the results of this work,; it can be concluded that biogas production from weeds is an ecologically and economically effective technology. Mathew *et al.* (2014) investigated thebiogas potential of aquatic weeds such as water hyacinth and salvinia which are locally available weeds in Santiniketan, West Bengal, India. The anaerobic process was carried out in batch mode at 2:1 inoculum to feedstock ratio over a period of 60 days using cow dung as an inoculum. Water hyacinth seems to be a promising feedstock for biogas production (552 $Lkg^{-1}VS$) in comparison to salvinia (221 $Lkg^{-1}VS$). They concluded from the experiment that a lower biogas yield obtained from salvinia might be due to lower biodegradability. Omondi *et al.* (2019) evaluated the co-digestion of Water Hyacinth (WH) biomass with various mix proportions of ruminal slaughterhouse waste (RSW) at 24, 32 and 37°C in order to assess the optimum proportion and temperature. The rate of biomethanation increased with temperature from 0.23 at 24ºC to 0.75 and 0.96 at 32ºC and 37ºC, respectively, and similarly methane yield improved from 14 at 24ºC to 40 and 52L/kg air dried water hyacinth at 32ºC and 37ºC respectively. A WH: RSW ratio of 30% showed optimum acclimatization and methane yield in a residence time of 60 days. The duration of the initial drop in pH that indicates hydrolysis stage decreased with increase in proportion of RSW, indicating faster hydrolysis and fermentation processes. Longer and stable latter alkaline pH zone suggested improved biomethanation and greater biogas production. Co-digestion with 30% RSW at 24ºC improved biogas yield by 75% from 8.05 to 14.09L/Kg biomass, methane component of biogas by 9% from 59 to 68% and reduced the retention time for substrate by 36%, suggesting synergy in co-digestion with respect to biogas quality. Changing the temperature from 24 to 32ºC increased the yield by 186% and reduced retention time by 73%. The results demonstrated synergy in co-digestion of the two substrates and the process dynamics that are useful in a possible process commercialization. Bote *et al*. (2020) studied that biogas production showed a different trend by mixing water hyacinth/dung. Biogas production between the fourth and the 18th day, there is lesser than dung but on the 32nd day, it grows rapidly to reach the maximum. For the mixture of hyacinth/cow dung, there is a delay in trends during the first few days, which shows that the microbial formation and their growth have to be improvised. The proportion of water hyacinth to cow dung has kept 1:1 which gives best yield as compared to 75-25 combination.

Biogas Production from Kitchen Wastes (Table 1C)

Lama *et al.* (2012) carried out the biodegradable study on kitchen wastes on modified ARTI model compact biogas plant of $1m^3$ digester and 0.75m gas holder at Kathmandu. The research was conducted in focusing the management of daily produced biodegradable wastes from households. The maximum methane gas was recorded as 65% and average maximum carbon dioxide was recorded as 58%. The daily temperature inside the digester was found in the range of (25-34°C) and pH value of the slurry was found in between (6.7-5.48). The average gas production was found to be 173 L/day. Since the daily feeding of 5kg dry kitchen waste produce 173 L of gas per day, per kg of kitchen waste can produce 35L of gas daily and concluded that this system will provide an appropriate and most efficient solution to the problem of kitchen waste enabling the recovery of energy from waste. Ahamed *et al.* (2016) performed research work to produce biogas from poultry and household (kitchen) waste using silica gel as a catalyst. A fabricated laboratory scale digester was used to generate biogas from the locally available waste obtained from poultry farms and domestic kitchens. Two laboratory-scale digesters were prepared to digest the solid wastes with and without silica, respectively. The operating temperatures of the digesters were maintained within 26°C-31°C. It was found that the production rate of biogas was increased while using silica gel as catalyst. The total gas production was found to be 7921 ml/kg of waste without silica gel whereas it was 10545 ml/kg with a maximum production rate of 1026 ml/kg in a day with silica gel as a catalyst and it was 33.12% hike in gas production. Kumar Vunduru Nooka Sai Vikram (2016) studied the co-digestion of kitchen waste and cow dung anaerobically revealed that theset2 (set2: 50gm grinded kitchen+150gm cow dung+water to make 1litre solution) with kitchen waste produces average 250.69% more gas than set 1 (set 1: 200gm cow dung+water to make 1litre slurry) and 67.5% more gas than set3 (set3: 400gm cow dung+water to make 2litre slurry). Means kitchen waste produces more gas than cow dung as kitchen waste contains more available nutrients than cow dung. So use of kitchen waste provides more efficient method of biogas production. Gebretsadik *et al.* (2018) observed that by using the simple and compact biogas digester, 10kg of kitchen waste was produced 2.292 m^3 of gas if there is ambient environment like optimum temperature conditions (greater than 26°C), pH (6.8-7.7), percentage of total solids (greater than 12%) and particle size of less than 1 cm. By storing the 2-3 days' produced gas it will be equivalent to consumption of 1 days LPG gas. So, anaerobic digestion of kitchen waste using simple and compact digester is a more feasible proven technology and economical for hotels and households in urban areas. Finally, it is highly recommended that this simple and compact digester can be used in rural regions preferably using animal feeds. Mutesasira *et al.* (2019) revealed from their study that the cogeneration slurries showed higher average rates of decomposition than single substrate slurries of cow dung (cd) or kitech waste food (kwf). The rate of gas evolution reached 5mL/day on the 15^{th} day using 25% cd mixed slurry. The rates of degradation attained in the mixtures were 1.42ml/g for cd; 1.58mL/g for kwf; 1.78mL/g for 75% cd mixed substrate; 1.78mL/g for 50% cd mixed substrate; 1.92mL/g for 25% cd mixed substrate slurries. The comparative rate of biogas formation ranged from1.25 to 1.35 which was in agreement with the range published in literature of 0.8 to 5.5. Siddharth *et al.* (2020) demonstrated a pilot study experimentation on biodegradable kitchen wastes to generate biogas under a fixed drum type model. They found that 75:25 ratio of food waste and cow dung provided more efficient gas i.e. around 4500ml biogas daily in a 8 litre digester or reactor.

Biogas production from crops and agriculture residues (Table 1D)

Iscia and Demirerb (2007) studied that the anaerobic treat ability and methane generation potential of three different cotton wastes namely, cotton stalks, cotton seed hull and cotton oil cake were determined in batch reactors. In addition, the effects of nutrient and trace metal supplementation were also investigated. To this purpose biochemical methane potential (BMP) experiments were performed for two different waste concentrations, namely 30 and 60 g/l. The results revealed that cotton wastes can be treated an aerobically and are a good source of biogas. Approximately 65, 86 and 78 ml CH_4 were produced in 23 days from 1g of cotton stalks, cotton seed hull and cotton oil cake in the presence of basal medium (BM), respectively. BM supplementation had an important positive effect on the production of biogas. Ilaboya *et al.* (2010)investigated the importance of biogas as an alternative energy sources. A survey was done to ascertain the amount of biogas that can be generated from various feed stock. A practical laboratory scale experimental design using agricultural waste was also done to find out the effects of Alkaline (NaOH) on the volume of biogas generated using a mixture of pineapple, plantain and cassava peelings as the feed stock. Results revealed a high volume of gas generated when the operating conditions inside the digester is maintained at moderately alkaline condition. Further findings also reveal that the digester temperature remained within the range of 27 to 35.5°C throughout the period of experimentation. When the pH of the system is maintained at that of clean fuels from biomass, sewage, urban, refuse prevalent for 3% wt/wt caustic treatment, more gas will be agricultural wastes. Xue *et al.* (2017) performed a continuous batch test study at 35°C to assess the methane production potential and volatile organic acid contents from crop straw using the modified Gompertz equation. The results showed that the biogas production from silage maize straw, rice straw, dry maize straw, and tobacco straw was in the order silage maize straw > rice straw > dry maize straw >tobacco straw, and the values were 1,166.7, 1,048.4, 890, and 637.4 ml/g ·VS, respectively. Silage maize is useful for biogas production because it contains four kinds of straw. Pavliukh *et al.* (2019) evaluated the organic waste (corn, straw, branches, fallen leaves, potato peelings) for the biogas production in compliance with an acute need to reduce the consumption of traditional energy resources. The possibility of using organic waste for the biogas production was experimentally confirmed. The influence of the initial fractions size and the temperature on the biogas yield has been studied.

Among the investigated organic wastes the potato peelings, corn waste and fallen leaves were found to be the most productive in relation to the biogas yield (91.66, 81.81 and 63.13 m^3/kg, respectively). The yield of biogas produced from potato peelings was found to be the highest one. Grinding of raw materials and raising temperatures were observed the positive influencing factors in biogas production.

Biogas from landfill waste and sludge (Table 1E)

Minale and Worku (2014) conducted a laboratory scale batch anaerobic co-digestion of sanitary wastewater wastes and kitchen organic solid waste with different mix ratio of 100:0, 75:25, 50:50, 25:75, and 0:100 by volume [sanitary wastewater (TS= 7,068 mg/L):kitchen organic solid waste (TS= 56, 084 mg/L)] were carried out at ambient temperature for 30 days. The amount of biogas and methane produced over the digestion period for those mixing ratios were compared. The highest biogas yield obtained from a mix ratio of 25:75 was 65.6 L, and the lowest from a mix ratio of 100:0 was 9.5 L. The percentage of methane gas in the biogas was between 19.8 and 52.8 %. It is also evidenced from the study results that the mixing ratio 25:75 produced the maximum quantity of biogas and methane. With regard to the fertilizer potential of the digested sludge, composting and sun drying process were helpful for land application by inactivating the pathogen. Laskri and Nedjah (2015) carried out anaerobic digestion of two biodegradable wastes from landfill and sludge from the wastewater treatment plant by natural lagoon separately in a digester with a capacity one liter, sealed. The biogas produced from the anaerobic digestion of the two substrates is flammable with a percentage of CH_4 more than 64%. Comparing the volume of biogas produced during the digestion of the two substrates of digestion they found that the volume collected from the sludge waste is 10 times greater than the volume of biogas produced with organic matter in the landfill. Agani *et al.*(2016) investigated that when anaerobic digestion applied to fecal sludge, it doesn't yield good methane due to its high content of nitrogen. When anaerobic digestion of fecal sludge was carried out in the presence of iron powder (Fe) as electron donor which resulted in to 4822.7mL CH_4 kg^{-1} was successfully recovered from fecal sludge as a control (fecal sludge). The use of Fe in the anaerobic bio-digester remarkably improved methane yield. Indeed, up to 9933.3mL CH_4 kg^{-1} wet sludge was recovered when Fe is properly used (1g Fe for 400 g wet weight), compared to 4822.7mL kg^{-1} in the control. The concentration of methane in the produced biogas increased from 58.0% in the control to 72.5% and 77.6% in the presence of iron powder, respectively at the dose rate of 0.5g Fe and 1g Fe per 400g wet sludge. Soyingbe *et al.*(2019)evaluated biogas production efficiency from faecal sludge and its combination with three feed stocks (cow dung, cow intestinal waste and mixed organic waste) were fed into a 2m^3 capacity digester to mix with faecal sludge for biogas production. Standard methods were used to determine chemical and biological qualities of influent and effluent slurries. The biogas produced was analyzed using multi-gas analyzer to determine the concentrations of CO, CO_2, CH_4 and H_2S. Methane formed major component of the biogas produced by all the substrates (40-70%).The study concluded that faecal sludge co-digested with various types of organic feedstock materials was effective in producing biogas and nutrient rich bio-slurries as organic fertilizer.

Table 1: Biogas production from different biomass sources.

A: Biogas production from cow dung, poultry waste, swine and plant wastes						
Biomass	**Inoculum**	**Operational Condition**	**Type of reactor**	**Pretreat-ment**	**Biogas Yield**	**References**
Cow dung, poultry waste and water hyacinth	-	33.5°C	batch type fixed dome biogas plant	-	• 34ml/g from cow dung • 58ml/g from poultry waste • 14ml/g from water hyacinth	Imam *et al.* (2013)
Poultry waste Fish waste Cow dung	Cow dung	Ambient temperature	20 litre water cans batch type	-	• 2.75cm rise in level of barine solution from mixture of poultry waste and cow dung, 6.2cm rise from the mixture of poultry waste, fish waste and cow dung on fifteenth day.	Sangeetha *et al.* (2014)

Groundnut Shell [GS], Maize Cob [MC], Rice Straw [RS] and Sugarcane Bagasse [SB])	Cow dung and poultry droppings	33 – 35°C	batch type fixed dome biogas plant	-	• 14.53 ml/g VM from [GS] • 22.32 ml/g VM from [MC] • 31.50 ml/g VM from [RS] • 8.08 ml/g VM from [SB])	Yavini *et al.,* (2014)
Piglet manure	Cow dung	37°C	Batch reactor	-	Piglet manure produced the highest methane yield at 443 Normal litter (NL) CH_4 (kg VS^{-1}) as compared to manure of sows, rabbits, goats, buffaloes as well as plant sources such as duckweed (*Spirodela polyrrhiza*), lawn grass and water spinach.	Cu *et al.* (2015)
Cow Dung (CD), Rumen(RU), Agar Waste (AW) and Sewage Sludge(SS)	-	Ambient temperature	Batch digester (2.5 litre)		1:1:1 ratio of RU:AW:SS. provides the highest biogas yield of 3886.30ml/L	Manimuthu *et al.* (2017)
Justicia schimperiana (JS) and cow dung	Cow's rumen juice	Ambient temperature	Batch reactor of 2 litre capacity gallon		Maximum biogas (3580 ± 8.5 ml) with maximum methane composition (69%) i.e., 2:1 ratio of cow dung to JS.	Yitayal *et al.* (2017)
Co-digestion of poultry manure, cow dung and vegetable waste.	-	37°C	Fixed dome type bio-digester	-	Cow dung with poultry waste observed maximum production of biogas is released at 13th day i.e.0.063 m^3.	Rekha et al. (2019)
Cow dung as animal waste, kitchen waste (food waste) trees waste (green waste)	-	Ambient temperature	Batch digester (15.12 litres)	-	Animal, kitchen and trees wastes 0.03 m^3, 0.024 m^3 and 0.0103 m^3 respectively.	Lakkimsetty and Mushaarafi(2019)
B: Biogas production from Weeds						
Pteris longifolia (DhekiShak) and Water Hyacinths, Cow dung, Bran	Cow dung	Ambient temperature	Batch Process and Continuous process	-	Mixture of the weeds yields 2018ml/kg while cow dung 1375ml/kg (batch process) average gas production is 915ml Water Hyacinths from (continuous process) average gas production is 2380ml Dheki Shak from (continuous process) Mixture of the weeds yields 5600 ml/kg (continuous process)	Islam*et al.* (2012)
Water hyacinth and salvinia	Cow dung	37±2°C	Batch digester	-	Biogas from salvinia were 552 L/kg volatile solids (VS) and 221 L kg/VS	Mathew et al (2014)

Water hyacinth and Ruminal slaughterhouse waste	-	24 °C, 32°C and 37 °C	1Litre flask	-	Ruminal Slaughter house waste alone (100% RSW) (17.8L CH_4/kg substrate) followed by 50% and 30% RSW while the smallest yield was for water hyacinth alone (0% RSW) at 8 L CH_4/kg substrate.	Omondi et al (2019)
Water hyacinth	Cow dung	23-40 °C	continuous type (10kg capacity digestor)	-	0.26 m^3	Bote *et al*. (2020)
C:Biogas Production from Kitchen Food Waste						
Kitchen wastes and cow dung	-	Ambient temperature (25-34°C)	ARTI model compact biogas plant		173 L/day	Lama *et al*. (2012)
Kitchen waste and chicken droppings	-	Ambient temperature	small conical flask in laboratoy		Total gas 10545 ml/kg with silica gel as a catalyst with 33.12% hike in gas production	Ahamed *et al.* (2016)
Kitchen wastes	Cow dung	Ambient temperature	1 litre and 2 litre bottles	-	0.85ml/g (set-1) 3.3 ml/g (set-2) 2.2 ml/g (set-3)	Kumar Vunduru Nooka Sai Vikram (2016)
Kitchen wastes	Cow dung	Average temperature 30.5°C, 25.5°C, 21°C and 17°C for (set-1) received sunlight 11hr/day (set-2) received sunlight 5hr/day (set-3) placed at dark And one set placed at Debre Berhan condition respectively.	Batch digester		2.292m^3 /10kg (set-1) 1.783 m^3 /10kg (set-2) 1.172 m^3 /10kg (set-3) 0.962m^3 /10kg (digester in Debre Berhan)	Gebretsadik *et al.* (2018)
Cattle dung, Cattle urine and garbage from dumping site	Sludge	Ambient temperature	Batch digester		431.5+4.65ml/L for 25% cow dung and 75% kitchen food waste	Mutesasira *et al.* (2019)
Kitchen wastes	Cow dung	37°C	Fixed dome type	-	75:25 ratio of food waste and cow dung 4500ml biogas daily in a 8 litre	Siddharth *et al.* (2020)
D: Biogas production from crops and agriculture residues						
Cotton stalks, cotton seed hull and cotton oil	-	Ambient temperature	Batch reactor	-	65, 86 and 78 ml CH_4 produced in 23 days from 1g of cotton stalks, cotton seed hull and cotton oil cake	Iscia and Demirerb (2007)
Pineapple peels, plantain and cassava peels	-	Ambient temperature	Batch reactor	1,3 and 5% wt/wt sodium hydroxide	10.22 cm^3/kg/day without sodium hydroxide 25.7 cm^3/kg/day with 3% sodium hydroxide	Ilaboya *et al.* (2010)

					$14.8 cm^3$/kg/day with 1% sodium hydroxide $13.6 cm^3$/kg/day with 5% sodium hydroxide	
Organic waste (corn, straw, branches, fallen leaves, potato peelings)	-	15-18°C, 18-20°C and 20-23°C	-	-	The highest biogas production value (91.66 m^3/t) from Potato peelings observed.	Pavliukh *et al.* (2019)
Silage maize straw, rice straw, dry maize straw, and tobacco straw	Cow manure	35°C	Batch reactor	180 days for silage	Silage maize straw 1,166.7 ml/g ·VS Rice straw 1,048.4 ml/g ·VS Dry maize straw 890 ml/g ·VS Tobacco straw 637.4 ml/g ·VS	Xue *et al.* (2017)
E: Biogas from landfill waste and sludge						
Sanitary wastewater wastes and kitchen organic solid waste	Cow manure	Ambient temperature	Batch reactor		65.6 L (25:75) 9.5 L(100:0)	Minale and Worku (2014)
Fecal sludge	-	45°C	Batch reactor	fecal sludge was enriched with iron powder at different concentrations	9933.3mL CH_4 kg^{-1} with the use of iron powder 4822.7mL CH_4 kg^{-1} in fecal sludge only.	Agani *et al.* (2016)
Landfill and wastewater sludge	-	37°C	Batch reactor	-	Volume collected from the sludge waste is 10 times greater than the volume of biogas organic matter in the landfill.	Laskri and Nedjah (2015)
Fecal sludge feed stocks	-	Ambient temperature	Batch reactor	-	Faecal sludge co-digested with various types of organic feedstock materials was effective in producing biogas	Soyingbe *et al.* (2019)

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